Journal of Cosmology and Astroparticle Physics, 2017, vol.2017, N5

Weyl metrics and wormholes

Gibbons G., Volkov M.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2017 IOP Publishing Ltd and Sissa Medialab srl. We study solutions obtained via applying dualities and complexifications to the vacuum Weyl metrics generated by massive rods and by point masses. Rescaling them and extending to complex parameter values yields axially symmetric vacuum solutions containing singularities along circles that can be viewed as singular matter sources. These solutions have wormhole topology with several asymptotic regions interconnected by throats and their sources can be viewed as thin rings of negative tension encircling the throats. For a particular value of the ring tension the geometry becomes exactly flat although the topology remains non-trivial, so that the rings literally produce holes in flat space. To create a single ring wormhole of one metre radius one needs a negative energy equivalent to the mass of Jupiter. Further duality transformations dress the rings with the scalar field, either conventional or phantom. This gives rise to large classes of static, axially symmetric solutions, presumably including all previously known solutions for a gravity-coupled massless scalar field, as for example the spherically symmetric Bronnikov-Ellis wormholes with phantom scalar. The multi-wormholes contain infinite struts everywhere at the symmetry axes, apart from solutions with locally flat geometry.

http://dx.doi.org/10.1088/1475-7516/2017/05/039

Keywords

gravity, Wormholes

References

[1] A. Einstein and N. Rosen, 1935 The Particle Problem in the General Theory of Relativity, Phys. Rev. 48 73
[2] L. Flamm, 1916 Beitraege zur Einsteinschen Gravitationstheorie Zeit. Phys. XVII 448
[3] L. Flamm, 2015 Contributions to Einstein's theory of gravitation, Gen. Rel. Grav. 47 72
[4] G.W. Gibbons, 2015 Editorial note to: Ludwig Flamm, Contributions to Einstein's theory of gravitation, Gen. Rel. Grav. 47 71
[5] A. Einstein, B. Podolsky and N. Rosen, 1935 Can quantum mechanical description of physical reality be considered complete?, Phys. Rev. 47 777
[6] J. Maldacena and L. Susskind, 2013 Cool horizons for entangled black holes, Fortsch. Phys. 61 781 [1306.0533]
[7] C.W. Misner and J.A. Wheeler, 1957 Classical physics as geometry: Gravitation, electromagnetism, unquantized charge and mass as properties of curved empty space, Annals Phys. 2 525
[8] C.W. Misner, 1960 Wormhole Initial Conditions, Phys. Rev. 118 1110
[9] M. Cvetič, G.W. Gibbons and C.N. Pope, 2015 Super-Geometrodynamics J. High Energy Phys. JHEP03(2015)029 [1411.1084]

[10] Virgo and LIGO Scientific collaborations, B.P. Abbott et al., 2016 Observation of Gravitational Waves from a Binary Black Hole Merger, Phys. Rev. Lett. 116 061102 [1602.03837]

[11] M.S. Morris, K.S. Thorne and U. Yurtsever, 1988 Wormholes, Time Machines and the Weak Energy Condition, Phys. Rev. Lett. 61 1446

[12] M. Visser, 1995 Lorentzian wormholes: From Einstein to Hawking, AIP, Woodbury U.S.A. [http://inspirehep.net/record/408164&inspirename]

[13] S.W. Hawking and G.F.R. Ellis, 2011 The Large Scale Structure of Space-Time, Cambridge Monographs on Mathematical Physics,Cambridge University Press

[14] J.L. Friedman, K. Schleich and D.M. Witt, 1993 Topological censorship, Phys. Rev. Lett. 71 1486 [Erratum i bid 75 (1995) 1872] [gr-qc/9305017]

[15] D. Hochberg and M. Visser, 1998 The Null energy condition in dynamic wormholes, Phys. Rev. Lett. 81 746 [gr-qc/9802048]

[16] K.A. Bronnikov, 1973 Scalar-tensor theory and scalar charge Acta Phys. Polon. B 4 251

[17] H.G. Ellis, 1973 Ether flow through a drainhole: A particle model in general relativity, J. Math. Phys. 14 104

[18] P. Kanti, B. Kleihaus and J. Kunz, 2011 Wormholes in Dilatonic Einstein-Gauss-Bonnet Theory, Phys. Rev. Lett. 107 271101 [1108.3003]

[19] K.A. Bronnikov and S.-W. Kim, 2003 Possible wormholes in a brane world, Phys. Rev. D 67 064027 [gr-qc/0212112]

[20] S.V. Sushkov and R. Korolev, 2012 Scalar wormholes with nonminimal derivative coupling, Class. Quant. Grav. 29 085008 [1111.3415]

[21] S.V. Sushkov and M.S. Volkov, 2015 Giant wormholes in ghost-free bigravity theory J. Cosmol. Astropart. Phys. 2015 06 017 [1502.03712]

[22] G. Clément, 1984 Axisymmetric Regular Multiwormhole Solutions in Five-dimensional General Relativity, Gen. Rel. Grav. 16 477

[23] H. Weyl, 1917 The theory of gravitation, Annalen Phys. 54 117

[24] G. Clément, 2016 Axisymmetric multiwormholes revisited, Gen. Rel. Grav. 48 76 [1511.06249]

[25] G. Clément, 1984 Regular multiparticle solutions of Einstein-Maxwell scalar field theories, Class. Quant. Grav. 1 275

[26] G. Clément, 1984 A class of stationary axisymmetric solutions of Einstein-Maxwell scalar field theories, Class. Quant. Grav. 1 283

[27] G. Clément, 1984 A Class of Wormhole Solutions to Higher Dimensional General Relativity, Gen. Rel. Grav. 16 131

[28] A. Chodos and S.L. Detweiler, 1982 Spherically Symmetric Solutions in Five-dimensional General Relativity, Gen. Rel. Grav. 14 879

[29] D. Zipoy, 1966 Topology of some spheroidal metrics, J. Math. Phys. 7 1137

[30] K.A. Bronnikov and J.C. Fabris, 1997 Weyl space-times and wormholes in D-dimensional Einstein and dilaton gravity, Class. Quant. Grav. 14 831 [gr-qc/9603037]

[31] G. Clément, 1999 Selfgravitating cosmic rings, Phys. Lett. B 449 12 [gr-qc/9808082]

[32] G. Clément, Spinning ring wormholes: A Classical model for elementary particles?, in proceedings of the 4th Alexander Friedmann International Seminar on Gravitation and Cosmology, St. Petersburg, Russia, 17-25 June 1998 [gr-qc/9810075]

[33] G.W. Gibbons and M.S. Volkov, 2016 Ring wormholes via duality rotations, Phys. Lett. B 760 324 [1606.04879]

[34] T. Tahamtan and O. Svitek, 2016 Properties of Robinson-Trautman solution with scalar hair, Phys. Rev. D 94 064031 [1603.07281]

[35] I.Z. Fisher, 1948 Scalar mesostatic field with regard for gravitational effects Zh. Eksp. Teor. Fiz. 18 636 [gr-qc/9911008]

[36] A.I. Janis, E.T. Newman and J. Winicour, 1968 Reality of the Schwarzschild Singularity, Phys. Rev. Lett. 20 878

[37] S. Abdolrahimi and A.A. Shoom, 2010 Analysis of the Fisher solution, Phys. Rev. D 81 024035 [0911.5380]

[38] G.W. Gibbons, Phantom matter and the cosmological constant, [hep-th/0302199]

[39] A. Peres, 1970 Gravitational field of a tachyon, Phys. Lett. A 7 361

[40] L.S. Schulman, 1971 Gravitational shock waves from tachyons, Nuovo Cim. B 2 38

[41] J.R. Gott, 1974 Tachyon singularity: A spacelike counterpart of the Schwarzschild black hole, Nuovo Cim. B 22 49

[42] G.W. Gibbons and D.A. Rasheed, 1996 Dyson pairs and zero mass black holes, Nucl. Phys. B 476 515 [hep-th/9604177]

[43] W. Israel and K. Khan, 1964 Collinear particles and Bondi dipoles in General Relativity, Nuovo Cim. XXXIII 331

[44] J. Chazy, 1924 Sur le champ de gravitation de deux masses fixées dans la théorie de la relativité Bull. Soc. Math. Fr. 52 17

[45] H. Curzon, 1924 Cylindrical solutions of Einstein's gravitational equations Proc Lond. Math. Soc. 25 477

[46] L. Silberstein, 1936 Two-Centers Solution of the Gravitational Field Equations and the Need for a Reformed Theory of Matter, Phys. Rev. 49 268

[47] N. Schleifer, 1985 Condition of elementary flatness and the two-particle Curzon solution, Phys. Lett. A 112 204

[48] A. Papaetrou, 1947 A Static solution of the equations of the gravitational field for an arbitrary charge distribution Proc. Roy. Irish Acad. A 51 191

[49] S.D. Majumdar, 1947 A class of exact solutions of Einstein's field equations, Phys. Rev. 72 390

[50] B.H. Voorhees, 1970 Static axially symmetric gravitational fields, Phys. Rev. D 2 2119

[51] H. Kodama and W. Hikida, 2003 Global structure of the Zipoy-Voorhees-Weyl spacetime and the δ=2 Tomimatsu-Sato spacetime, Class. Quant. Grav. 20 5121 [gr-qc/0304064]

[52] G. Lukes-Gerakopoulos, 2012 The non-integrability of the Zipoy-Voorhees metric, Phys. Rev. D 86 044013 [1206.0660]

[53] A.I. Egorov, P.E. Kashargin and S.V. Sushkov, 2016 Scalar multi-wormholes, Class. Quant. Grav. 33 175011 [1603.09552]

[54] C. Schiller, 2006 Simple derivation of minimum length, minimum dipole moment and lack of space-time continuity, Int. J. Theor. Phys. 45 221

[55] G.W. Gibbons, 2002 The Maximum tension principle in general relativity, Found. Phys. 32 1891 [hep-th/0210109]

[56] S. Krasnikov, 2003 The Quantum inequalities do not forbid space-time shortcuts, Phys. Rev. D 67 104013 [gr-qc/0207057]

[57] M. Visser, 1989 Traversable wormholes: Some simple examples, Phys. Rev. D 39 3182 [0809.0907]

[58] T. Matos, 2010 Class of Einstein-Maxwell Phantom Fields: Rotating and Magnetised Wormholes, Gen. Rel. Grav. 42 1969 [0902.4439]

[59] P. Appell, Quelques remarques sur la théorie des potentiels multiformes, Math. Ann. 30 (1887) 155

[60] G. Miranda, T. Matos and N.M. Garcia, 2014 Kerr-Like Phantom Wormhole, Gen. Rel. Grav. 46 1613 [1303.2410]

[61] T. Matos, L.A. Urena-Lopez and G. Miranda, 2016 Wormhole Cosmic Censorship, Gen. Rel. Grav. 48 61 [1203.4801]

[62] R. Gleiser and J. Pullin, 1989 Appell rings in general relativity, Class. Quant. Grav. 6 977

[63] P.S. Letelier and S.R. Oliveira, 1998 Superposition of Weyl solutions: The Equilibrium forces, Class. Quant. Grav. 15 421 [gr-qc/9710122]

[64] O. Semerák, 2016 Static axisymmetric rings in general relativity: How diverse they are, Phys. Rev. D 94 104021 [1611.03299]

[65] B. Carter, 1968 Global structure of the Kerr family of gravitational fields, Phys. Rev. 174 1559

[66] G. Clément, D. Gal'tsov and M. Guenouche, 2016 NUT wormholes, Phys. Rev. D 93 024048 [1509.07854]

[67] E. Ayon-Beato, F. Canfora and J. Zanelli, 2016 Analytic self-gravitating Skyrmions, cosmological bounces and AdS wormholes, Phys. Lett. B 752 201 [1509.02659]

[68] C. Fronsdal, 1959 Completion and Embedding of the Schwarzschild Solution, Phys. Rev. 116 778

[69] M. Ferraris and M. Francaviglia, 1979 An algebraic isometric embedding of Kruskal space-time, Gen. Rel. Grav. 10 283